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Analysis of skull asymmetry in different historical periods using radiological examinations

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Summary

Background: Asymmetry is a very common phenomenon in nature. Occurrence of asymmetry and knowledge of correct structure, especially a range of variability which is not a pathology but only an individual variation, are the basis for interpretation of results of radiological examination of the skulls both in research work and in diagnostic examinations, which are widely performed in modern medicine. There are many methods of estimation of the asymmetry. The aim of this study was to estimate the symmetry of skulls from selected historic populations.

Material/Methods: The studied material consisted of two skull populations – contemporary consisting of 82 skulls and medieval – 77 skulls from Gródek. X-rays in P-A and skull-base projections were performed. The images were scanned and calibrated by means of MicroStation 95 Academic Edition software. Using tools for measurement of vector elements, distances between selected bilateral points of the skull were taken. All data were analyzed statistically.

Results: Asymmetry was observed in the skulls of both populations. Some diameters were higher on the left side, some on the right side. High levels of asymmetry index in the superior facial part and in the posterior part of the skull base were observed. The levels of the asymmetry indexes in both groups were similar.

Conclusions: Radiological pictures in two projections should be taken for correct analysis of the skull asymmetry. The examination of the asymmetry of the landmarks should be based on the analysis of diameters from two different points of reference. The human skull does not demonstrate a clear domination of one side. The largest variations were observed in the shape and localization of the foramina of the skull . It is associated with the differences of the position of the neurovascular elements which pass through these foramina.

Key words: **skull • asymmetry • skull foramina**

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Background

Structure and symmetry of the skull and the head are assessed using various research methods. The oldest one involved the analysis of measurements taken with instruments used in anthropology on the head of a living subject or on the macerated skull. The pioneer of Polish studies of cranial and facial symmetry, Professor Wrzosek [1], asked the examined person to stand in a well-lit place and assessed facial symmetry imagining a line passing through the middle of the forehead and root of the nose. He distinguished two grades of asymmetry. Grade I asymmetry involved negligible differences, and grade II – marked difference between both sides. Stereophotometry [2, 3, 4] and analysis of photographs [5, 6, 7, 8, 9,10, 11] are other methods used for assessment of asymmetry. Comparison of photographs, despite the fact that it may seem old-fashioned or lack objectivity, has been used up to the present. Opitz [8] analyzing the phenomenon of asymmetry, took photographs of people which were then cut along the median line to obtain pictures of the face consisting of two right and two left portions. The obtained pictures were considerably different from the original photo. Appenzeller [5], who investigated 200 sepulchral portraits from Egypt, dating back to the early years of the millenium and 32 Egyptian skulls, also used this method. Modern methods involve analysis of images obtained with a digital camera using Bezier curves and screen technique [7].

In the early 20th century, the application of radiography in assessment of cranial symmetry became popular both with physicians, who perceived it as a new tool for evaluation of the patient's condition, and with paleopathologists. Ellioth Smith, who used X-ray in 1904 to examine the mummy of Tuthmosis IV, was the precursor of this method. Examination of archeological exhibits with X-ray proved very to be a valuable method because of its non-invasive character and potential to visualize the internal structure of unique materials [12, 13].

Cranial symmetry analysis is indispensable in many fields of medicine. In dental surgery, it is concerned primarily with the elements of the facial skeleton [14, 15, 16], the mandible [17, 18], teeth [19, 20, 21] or the temporomandibular joint [22]. Precise measurements of facial skeleton symmetry are recommended in orthodontics for diagnostic purposes and treatment planning. Björk [14] noted that size and shape of the skull base determines those of the maxilla nad mandible, and consequently the occlusal conditions.

Anatomy of the skull base is very important for neurologists, radiologists and neurosurgeons [23]. Besides direct head measurements, radiological techniques are used for assessment of cranial and craniofacial symmetry – both conventional X-ray radiography and the latest computed tomography (CT) or magnetic resonance (MR) techniques [5, 23, 24, 25, 26, 27]. The knowledge of variations in skull base shape is indispensable not only for understanding of the anatomy of neuromuscular structures, but also for differentiation of normal structures from potentially pathological ones. Ginsberg [24], who examined with CT the foramen rotundum, ovale, spinosum, sphenopalatine, the emissary foramen and the innominate canaliculus found the variations of the foramen spinosus to be associated with anomalies of osteogenesis or development of the middle meningeal artery. He observed asymmetry in the shape and location of all these foramina. Lanzieri [25] found that asymmetry of the sphenoid emissary vein foramen is more frequently associated with pathologies than with normal conditions. The shape and size of the middle cranial fossa can be influenced, among others, by tumors, vascular anomalies, diseases affecting the margins of cranial foramina, Paget disease, osteoporosis [26]. Hadźiselmović [28] and Geschwind [29] observed that the skull base morphology is dependent on the changes of morphological structures and position of the temporal bone. The aim of the study was to assess and compare the symmetry of two polulations of skulls – a contemporary and a historic one – using traditional radiographic methods.

Materials and methods

The research material consisted of two skull populations: 77 medieval skulls found in Gródek on the Bug River from the collection of the Chair of Anthropology of the University of Wrocław and 82 contemporary skulls dating back to the early 20th century from the museal collection of the Chair of Normal Anatomy of PMU in Szczecin.

All the examined skulls were male. Their preservation grade was described as *cranium* and *calvarium.* The subjects' age at the time of death, determined on the basis of cranial sutures ossification, was described as *adultus* and *maturus.* Plain X-ray radiograms of all specimens were obtained in modified universal P-A projection proposed by Caldwell [acc. to 30] and in the basal projection – clinically referred to as parieto-submental. To ensure comparability of skull measurement results, the radiograms were taken with constant focus – film distance. According to recommendations by Zborowski and Piontek [31], this distance was 100 cm. All the radiograms were made by the same person, with no diffusion box and enhancement foil, in order to obtain the best possible quality. Polystyrene foam pads were used to ensure symmetrical positioning of the skulls for radiography. The radiograms were scanned and subjected to calibration using MicroStation 95 Academic Edition software.

Geometrical transformation with grade I (Helmert) multinomial was performed. The reference material prepared in this way was subjected to vectorization of axes and field borderlines. Using the instruments for measurement of vector elements, the distances between selected bilateral points on the skull were measured. The distance of these points from the median line and to the second reference point located on the median line. The median line plotted on P-A projection images, passed through the *vertex (v), nasion (n) i prosthion (pr)* points. In basal projection images, the median line was plotted through the following points: *opisthokranion (op), opisthion (o), basion (ba), sphenobasion (sphba)* and *orale (ol).*

On films obtained in P-A projection, the following distances were measured (fig. 1):

1. v-eu = vertex – euryon,
2. eu-lp = euryon – median line,
3. v-fmt = vertex – frontomalare temporale,
4. fmt-lp = frontomalare temporale – median line,
5. fmt-pr = frontomalare temporale – prosthion,
6. n-apt = nasion – aperthion,
7. apt-lp = aperthion – median line,
8. n-mf = nasion – maxillofrontale,
9. mf-lp = maxillofrontale – median line,
10. mf-ek = maxillofrontale – ektokonchion,
11. spa-sbk = suprakonchion – subkonchion,
12. p.oczod = orbit surface area

On films obtained in basal projection, the following measurements were performed bilaterally (fig. 2):

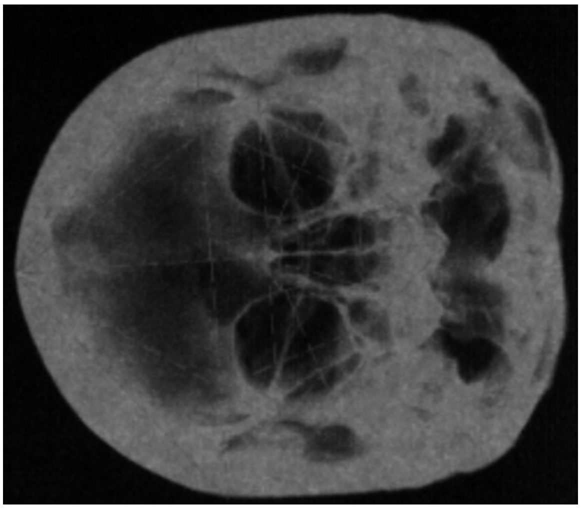

Figure 1. Vector axes of the radiologic image drawn on the P-A projection.

13. op-eu = opisthokranion – euryon,
14. eu-lp = euryon – median line,
15. op-ast m = opisthokranion – asterion
16. ast m-lp = asterion – median line,
17. ast m-sphba = asterion – sphenobasion,
18. sphba-spal = sphenobasion - palatinolaterale,
19. spal-lp = palatinolaterale – median line
20. spal-ol = palatinolaterale – orale,
21. fol-lp = foraminolaterale – median line,
22. ½ f.mag = half surface area of foramen magnum,
23. ba-f.o = basion – foramen ovale,
24. ba-f.s = basion – foramen spinosum,
25. lp-f.o = median line – foramen ovale,
26. lp-f.s = median line – foramen spinosum,
27. p.f.o = surface area of foramen ovale,
28. p.f.s = surface area of foramen spinosum,
29. dł.pir. = pyramid length,
30. <pir = angle between long axis of the pyramid and median line

In total, 60 measurements of each skull were taken on the radiograms: 12 bilateral on films obtained in P-A projection, 18 bilateral on films obtained in basal projection. Seven measurements characterized the cranial vault, 9 the facial skeleton and 14 the skull base.

Asymmetry was estimated using the asymmetry index according to Rossi

(R-L) x 100 / R, where R represents the measurement taken on the left side, L – on the left side [32].

Statistical analysis

In descriptive data analysis, the arithmetic mean, median, minimum, maximum and standard deviations vare calculated. Distribution normality was checked using Shapiro-Wilk W test, and variance homogeneity – with Fisher F test.

If the distribution was normal and variance homogeneous, inter-group comparison of parameters was carried out using student-t test, in other cases – with Mann-Whitney U test. Intra-group comparison of right- and left-sided dimensions was carried out using student-t test for dependent variables and its nonparametric counterpart – Wilcoxon paired rank test.

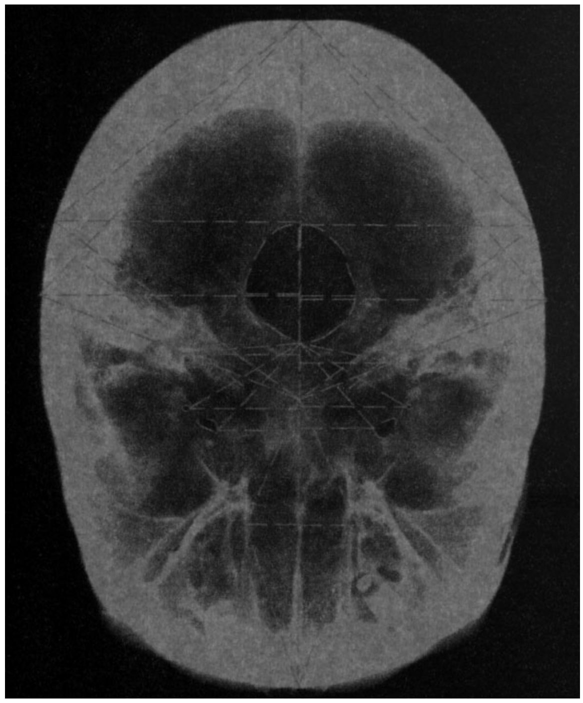

Figure 2. Vector axes of the radiologic image drawn on the skull base projection.

The adopted statistical significance level was $p < 0.05$.

Results

A. Contemporary skulls:

The asymmetry index values calculated for contemporary skulls are presented in table 1. Minus indicates dominance of left over the right side. Such dominance occurs with respect to 9 parameters measured on the skull base and 6 measured on radiograms performed in P-A projection. The calculated asymmetry index indicated significantly larger dimensions of the posterior crannial fossa region on the left side, including the size of the examined foramina – ovale and spinosum. Most dominating left-sided measurements – in 76% of the skulls – were noted with respect to mf-lp distance, describing orbit width. Also the width of the nose was significantly larger on the left side. The lower portion of the facial skeleton, characterized both by the dimension measured on basal projection radiograms and in P-A radiograms, demonstrates dominance of the right side. The highest asymmetry index values were obtained for the foramen spinosum.

B. Medieval skulls from Gródek:

In the population of medieval skulls from Gródek on the Bug River, right-sided measurements yielded in most cases higher values than left-sided ones (tab. 2). Cranial vault dimensions show dominance of the right side. On skull bases, significantly larger dimensions of the foramen ovale and asymetric locations of the ovale and spinosum foramina

Table 1. Asymmetry index values for contemporary skulls.

Dimension / Unit	N	Mean	Mediana	Minimum	Maximum	Standard deviation	W	p
op-eu (mm)	76	0,366395	0,714147	-15,4047	17,47492	7,696351	0,960521	0,06096
eu-lp (mm)	76	-0,119930	0,666071	-28,0884	24,45981	13,66445	0,925118	0,000158
op-ast m (mm)	76	-0,385710	-0,197010	-17,9634	13,65788	7,845163	0,958735	0,046736
ast m-lp (mm)	76	-0,520980	0,500208	-31,0030	24,45981	13,62199	0,945315	0,005432
ast m-sphba (mm)	76	0,125698	1,409576	-52,4781	41,66020	12,27774	0,920487	6,87E-05
sphba-spal (mm)	76	1,076463	-0,001160	-13,7421	21,41328	6,591405	0,961757	0,072997
spal-lp (mm)	76	0,736849	0,462963	-48,0769	38,00000	19,09243	0,978364	0,531673
spal-ol (mm)	76	0,303655	0,475823	-5,90631	7,363420	2,831961	0,965964	0,131312
fol-lp (mm)	76	-0,921620	-0,636970	-31,5789	34,00810	15,35922	0,970513	0,234527
½ p.f.mag (mm^2)	72	-3,875770	-1,729100	-48,8688	34,16105	18,12064	0,971930	0,296165
ba-f.o (mm)	64	-1,606730	-0,336060	-70,0000	17,37968	14,13897	0,860906	6,40E-08
ba-f.s (mm)	62	-0,373550	1,398888	-39,7683	23,96907	11,66907	0,950687	0,030335
lp-f.o (mm)	65	0,570000 8138,000	1,293103	-61,0465	38,11321	19,14707	0,956769	0,057138
lp-f.s (mm)	63	1,802593	1,583113	-35,5805	28,05970	13,64846	0,972376	0,360351
p.f.o (mm^2)	65	8,508586	11,74419	-96,3791	69,70980	33,15205	0,943710	0,009613
p.f.s (mm^2)	63	-32,52360	-12,90320	-273,913	70,96774	80,83254	0,825450	6,76E-10
dł. pir. (mm)	74	0,676645	1,479929	-26,7703	32,34450	11,42278	0,975725	0,425815
< pir (st)	75	-2,788430	-1,761250	-23,9075	21,80579	9,991085	0,978983	0,564311
v-eu (mm)	72	2,167828	1,952656	-11,9830	17,99463	4,258310	0,962421	0,091823
eu-lp p-a (mm)	74	4,529178	3,267660	-17,1018	50,57720	8,482547	0,852654	5,73E-10
v-fmt (mm)	72	-0,646290	-0,548920	-9,08108	6,875632	2,845330	0,982398	0,730959
fmt-lp (mm)	80	0,623639	0,093458	-9,60784	54,13534	7,016148	0,580784	1,53E-32
fmt-pr (mm)	79	0,801778	0,480192	-6,74764	40,45922	5,190092	0,568785	9,48E-33
n-apt (mm)	79	-0,060370	-0,581400	-15,1667	35,00000	5,862042	0,658261	3,24E-26
apt-lp (mm)	79	-4,329460	-2,659570	-64,1304	29,71429	18,16141	0,955496	0,024600
n-mf (mm)	80	-5,832980	-6,748470	-42,3358	51,06383	15,52007	0,978650	0,528330
mf-lp (mm)	80	-12,32670	-10,05160	-67,0000	19,78022	17,68798	0,972770	0,286795
mf-ek (mm)	80	2,309038	2,655544	-24,6753	17,41294	6,470429	0,952491	0,014165
spa-sbk (mm)	80	1,876489	1,507547	-9,01408	15,05882	4,845657	0,984674	0,806697
p.oczod mm2 (mm^2)	80	4,290655	3,552278	-12,7677	17,87131	5,852637	0,986575	0,877477

were demonstrated. The dimension which was most frequently larger on the left side was the distance between the mf point and the median line.

In this group the orbits were characterized by significant domination of the left-sided height. The highest asymmetry index values were obtained for the sizes of the ovale and spinosum foramina.

C. Comparative analysis of medieval and contemporary skulls:

The comparison of mean asymmetry index values obtained for medieval and contemporary skulls revealed statistically significant differences only with respect to 3 investigated parameters: n-apt, mf-lp and orbit surface ara (tab. 3). No statistically significant differences between the other parameters were noted.

Discussion

Assessment of cranial symmetry requires very precise and reproducible research methods. The analyzed material

Table 2. Asymmetry index values for mediaeval skulls.

Dimension / Unit	N	Mean	Mediana	Minimum	maximum	Standard deviation	W	p
op-eu (mm)	77	3,047066	1,929825	-13,7577	89,64912	10,67281	0,410408	9,46E-420
eu-lp (mm)	77	2,857899	3,889586	-37,7698	20,44693	8,100855	0,867435	2,93E-090
op-ast m (mm)	77	1,817877	1,885099	-13,7577	11,91088	4,009630	0,976126	0,4284460
ast m-lp (mm)	77	3,782976	3,387704	-25,3237	23,94366	7,280097	0,960027	0,0545390
ast m-sphba (mm)	77	2,948379	2,512563	-16,1036	20,11236	5,900384	0,952872	0,0177990
sphba-spal (mm)	77	1,171539	2,173913	-11,3757	15,21127	5,517534	0,975826	0,4158990
spal-lp (mm)	77	2,632174	3,846154	-56,4626	38,73874	17,33813	0,976617	0,4493810
spal-ol (mm)	77	-0,036900	0,505902	-38,8471	8,607595	5,364877	0,630999	3,8E-2700
fol-lp (mm)	77	-2,476910	-2,585910	-62,9921	17,85714	15,55710	0,895407	5,55E-070
½ p.f.mag (mm^2)	76	-2,896050	1,256206	-82,3946	28,48338	20,32749	0,935943	0,0010850
ba-f.o (mm)	74	-0,101460	-0,201460	-43,3333	30,62827	9,313402	0,897337	1,53E-060
ba-f.s (mm)	71	0,519678	0,290698	-23,8710	19,08213	7,885654	0,955794	0,0378010
lp-f.o (mm)	74	1,623824	3,716921	-60,2094	26,42857	14,35862	0,845802	1,73E-100
lp-f.s (mm)	71	1,721123	1,869159	-26,8657	25,85670	9,410069	0,964517	0,1249310
p.f.o (mm^2)	71	-2,933180	5,752212	-251,825	63,87665	48,23215	0,808265	1,3E-1200
p.f.s (mm^2)	69	-44,05120	-1,639340	-17,0000	75,55556	211,8604	0,354958	1,42E-370
dł. pir. (mm)	77	2,535460	3,431373	-44,8326	22,56809	10,62905	0,927637	0,000220
< pir (st)	77	-0,955100	-0,604840	-39,0728	31,12245	11,21593	0,977664	0,495587
v-eu (mm)	74	3,576675	3,441860	-13,5593	18,46758	6,515202	0,979315	0,583756
eu-lp p-a (mm)	74	4,314634	4,874777	-15,198	19,69112	7,690519	0,975276	0,407572
v-fmt (mm)	74	0,204009	-0,142990	-9,76693	11,64444	3,917326	0,986177	0,873423
fmt-lp (mm)	74	-1,081460	0,084175	-40,8269	10,29412	7,538311	0,746842	1,02E-17
fmt-pr (mm)	74	-0,044340	0,060241	-9,12698	16,99883	3,866546	0,947139	0,008450
n-apt (mm)	74	0,732178	0,652714	-29,5964	11,11111	4,766745	0,712634	4,24E-20
apt-lp (mm)	74	-0,371880	-1,034730	-65,9091	41,13924	15,41002	0,959103	0,053535
n-mf (mm)	74	-5,646090	-3,531370	-50,0000	19,16168	13,14242	0,951962	0,018187
mf-lp (mm)	74	-9,076370	-2,032360	-134,483	26,47059	25,42217	0,81614	1,04E-12
mf-ek (mm)	74	1,840341	1,389575	-10,4558	14,17112	5,240144	0,981501	0,684309
spa-sbk (mm)	74	-0,167340	0,377204	-19,8391	14,84185	5,566432	0,967558	0,169954
p.oczod mm2 (mm^2)	74	1,480097	0,693040	-13,5428	26,62096	7,036595	0,948404	0,010357

must be examined under the same conditions, with the same ecuipment and measurement protocol. Currently, the use of radiological methods – plain radiography, computed tomography and magnetic resonance – is increasing [5, 16, 23, 24, 25, 27, 33, 34, 35, 36, 37, 38, 39, 40, 41]. Repeatable procedures allow objectivization of the collected data and their comparison with those obtained by other authors [40, 42]. In this study, to ensure the comparability of results accirding to the recommendations given by Zborowski and Piontek [31], the radiograms were taken with constant focus-film distance of 100 cm and constant parameters of the X-ray apparatus. The skulls were stabilized for examination on polystyrene foam pads. Stabilization of the specimens and their radiological examinations were performed by the same person for the whole series.

Researchers studying the phenomenon of asymmetry proposed that the radiograms should be taken in various projections. Zaborowski and Piontek [40] performed symmetry analyses on radiograms obtained in posteroanterion projection (P-A). Some studies of cranial asymmetry analyzed basal projection radiograms as well [33, 37]. Grayson [33] claimed that a combination of data from minimum two projections is necessary to obtain a complete picture of skull

Table 3. Comparison of the asymmetry index value between two groups.

Dimension / Unit	Contemporary skulls		Mediaeval skulls		p
	N	Mean	N	Mean	
op-eu (mm)	76	0,366395	77	3,047066	0,278478
eu-lp (mm)	76	-0,119930	77	2,857899	0,520728
op-ast m (mm)	76	-0,385710	77	1,817877	0,132276
ast m-lp (mm)	76	-0,520980	77	3,782976	0,162249
ast m-sphba (mm)	76	0,125698	77	2,948379	0,195189
sphba-spal (mm)	76	1,076463	77	1,171539	0,923018
spal-lp (mm)	76	0,736849	77	2,632174	0,521220
spal-ol (mm)	76	0,303655	77	-0,036900	0,976711
fol-lp (mm)	76	-0,921620	77	-2,476910	0,850936
½ p.f.mag (mm^2)	72	-3,875770	76	-2,896050	0,526734
ba-f.o (mm)	64	-1,606730	74	-0,101460	0,998297
ba-f.s (mm)	62	-0,373550	71	0,519678	0,888802
lp-f.o (mm)	65	0,578138	74	1,623824	0,889210
lp-f.s (mm)	63	1,802593	71	1,721123	0,797701
p.f.o (mm^2)	65	8,508586	71	-2,933180	0,163955
p.f.s (mm^2)	63	-32,52360	69	-44,05120	0,710415
dł. pir. (mm)	74	0,676645	77	2,535460	0,086519
< pir (st)	75	-2,788430	77	-0,955100	0,289429
v-eu (mm)	72	2,167828	74	3,576675	0,188455
eu-lp p-a (mm)	74	4,529178	74	4,314634	0,567722
v-fmt (mm)	72	-0,646290	74	0,204009	0,259621
fmt-lp (mm)	80	0,623639	74	-1,081460	0,890700
fmt-pr (mm)	79	0,801778	74	-0,044340	0,270220
n-apt (mm)	79	-0,060370	74	0,732178	0,000596
apt-lp (mm)	79	-4,329460	74	-0,371880	0,150314
n-mf (mm)	80	-5,832980	74	-5,646090	0,572661
mf-lp (mm)	80	-12,32670	74	-9,076370	0,029894
mf-ek (mm)	80	2,309038	74	1,840341	0,382487
spa-sbk (mm)	80	1,876489	74	-0,167340	0,016053
p.oczod mm2 (mm^2)	80	4,290655	74	1,480097	0,002548

asymmetry, owing to the possibility of examining cranial structures in two or more planes. Such an approach allows three-dimensional analysis. He used P-A and basal projection radiograms in his studies of cranial asymmetry. The same projections were used by Pirtiniemi and Kantomaa [43]. Mulick [44], Šmahel [45] and Ingerslev [34] correlated informtion obtained from P-A and lateral projections. In our study, radiograms taken in P-A and basal projections were used. The P-A projection was selected because it provides a possibility of accurate assessment of the cranial vault, bones of the facial skeleton, sinuses and orbits. Up to recent times, the radiograms of this type have been usually taken for diagnostics of patients with headaches, diseases affecting the paranasal sinuses and after head traumas, primarily in order to detect the presence of fractures (particularly orbital ones) [30, 46, 47, 48] and in dental surgery. Currently they tend to be replaced by CT, which also is a modality enabling symmetry analysis. Basal projection allows to visualize the neurovascular foramina, which are of interest to neurologists and neurosurgeons, for whom the anatomic relations in this area are crucial for analysis of the presentation of the diseass as well as for planning surgical procedures, and for that reason this projection was also selected.

The analysis of symmetry is based on comparison of both sides of the skull in relation to the median line. Many different reference points used for plotting the median line have been described in the literature [9, 16, 24, 25, 26, 38, 44, 49, 50, 51, 52, 53]. In the presented study, the median line was plotted according to Zaborowski and Piontek [31] on P-A projection radiograms through the following points: *vertex* (v), *crista gali*, *nasion* (n), and *prosthion* (pr), and on basal projection radiograms through *opisthocranion* (op), *opisthion* (o), *basion* (b), *sphenobasion* (sphb) and *orale* (o). The advantage of the selected lines is the possibility of their determinations both on radiograms of archeological material and in living patients. Another advantage is the possibility of symmetry analysis of the whole skull without the preliminary stage involving the orbits or the neurovascular foramina. There are many various methods of determination of median lines, as well as many methods of determination of bilateral points and detection of their asymmetry. These points should be easily identifiable, reproducible and should not undergo significant changes during the individual's development. Some researchers determine the symmetry of particular points only by assessing a single dimension [15, 37, 53, 54, 55, 56]. This method seems to be very unreliable because each point must have two reference sites. To avoid misinterpretation, Laspos [17], Skvarilova [49], Smahel [45], Molsted [16] and Mulick [44] measured the distance of selected cranial points from the medial line and from a perpendicular line passing throung the left Lo point (point of intersection of the innominate line with the upper orbital margin). Also Pirttiniemi and Kantomaa [22] as well as Mulick [44] used two axes as a reference. The method of triangles was used by Vig and Hewitt [38], Skvarilova [57], Keleş [58], Shah [59]. On the basis of experience of the aforementioned researchers, the method of assessment of point asymmenty based on measurement of two distances was used as the easiest and the most objective one. The first measurement was taken between the analyzed point and the reference point on the median line, and the second was the distace from the median line itself, measured perpendicularly to that line. The symmetry is ideal if the distances for bilateral points are identical on both sides of the skull. This method seems to be the simplest to use in standard radiological diagnostics.

One of the first and most remarkable studies of morphological cranial asymmetry up to the present was the study by Woo [60]. On the basis of examinations of 800 Egyptian skulls, he concluded that the human skull is naturally asymmetrical with the tendency of dominance of the right-sided dimensions. He observed left-sided doninance of some measurements in the region of the skull base and face, which is consistent with our material – the dimensions of the foramen spinosum were significantly larger and it was situated further from the median line on the left side.

Right-sided dominance in more common in the analyzed skull populations, both with respect to the number of skulls, and with respect to the number of individual measurements. The cranial vault, as reported by Woo [60], demonstrated dominance of right-sided dimensions, and left-sided dominance was observed within the facial skeleton and skull base region. Asymmetry indexes in both skull populations differed significantly for 3 parameters only: n-apt, mf-lp, and orbital surface area. In medieval skulls n-apt distance was longer on the right side, and in contemporary ones on the left, mf-lp dominates on the left side in both groups, but its values are significantly higher in medieval skulls, orbit surface area is larger on the right side in both groups, and, additionally, significantly larger in medieval than in contemporary skulls. The above differences are probably associated with more frequent occurrence of narrow-faced forms in the contemporary group, and predominance of medium- width- and wide-faced forms among the medieval skulls.

The skull base is the region of interest for many researchers. It is associated with interdisciplinary functions of the area. The knowledge of topography and variability of the spinosum and ovale foramina is very different in surgical procedures performed from the lateral approach to the cavernous sinus. It allows, among others, to avoid some intra- and postoperative complications, such as paralysis of the trigeminal nerve. Pirttiniemi [22] observed on the basis of analyzed material consisting of Saami skulls that the articular fossa and adjacent points of the skull base on the right are located more laterally and distally on the right side than on the left one. The foramen spinosum is further from the median line on the right. The analyses were based on P-A and basal projection radiograms. In own research, we also observed the asymmetry of shape, size and location of the ovale and spinosum foramina in both skull populations, as well as very high value of asymmetry indexes obtained for these structures. In both groups, the surface area of the foramen spinosum as found to be significantly larger on the right sides, whereas the foramen ovale is larger on the right side in contemporary skulls, and on the left in the medieval ones. The oval foramina are located more anteriorly and medially on the left side in both groups. The foramen spinosum, like in Pirtini's study, is located more laterally on the right side. In medieval skulls, its location is more anterior on the right, and in contemporary ones on the left side, whereas on the right it tends to be more posterior. Ginsberg [24], assessing the foramina: rotundum, ovale, spinosum, sphenopalatine, the emissary foramen and the innominate canaliculus in head CT, observed asymmetry in shape of the oval foramina in 23.5% of patients, and in their size in 30.9%. The location of the foramen rotundum showed no variability. Own studies revealed also significant differences in the shape and size of the foramen ovale and foramen spinosum. Berge and Bergman assessed the size of the cranial foramina with CT and MR. They observed considerable variability of shape and size of the foramen ovale and foramen spinosum. Our results confirm that observation.

Right-sided dominance of skull base dimensions was observed by Lee [61], who studied the anatomy of anterior clinoid processes. As a result of anlysis of radiograms using the triangle method, Vig [38] concluded that the region of the skull base and mandible is larger on the left. Identical results were obtained by Mulick [44]. In our studies, no unequivocal dominance of either side was observed.

Asymmetry is expressed not only by variability of location and size of the neurovascular foramina. The posterior part of the skull base is wider on the left in contemporary skulls (eu-lp, op-ast m) and on the right in medieval ones. In contemporary skulls, the angle between the long axis of the temporal pyramid and the median line is also significantly wider on the left. The anterior part of the skull base, measured as the width and length of the palate (spal-lp, spal-ol, spha-spal), has larger dimensions on the right both in contemporary and in medieval skulls. Analysis of facial skeleton elements in the studied material demonstrates moderate dominance of the right side in contemporary skulls – 5 out of 9 analyzed parameters, and of the left side in medieval skulls – 6 out of 9 analyzed parameters are higher on this side. In contemporary skulls, higher values are obtained for parameters characterizing the orbit region (width, height, surface area) whereas the nasal incisure is more pronounced on the left side. Škvarilova [49] obtained similar results in the analysis of asymmetry of the anterior cranial surface in radiograms of contemporary living male subjects. Thus, such spatial relationships are characteristic of the contemporary populations. The results of measurements of the piriform aperture in the study by Mølsted [16] also demonstrate left-sided dominance. In medieval skulls, the dimensions of the piriform aperture demonstrate higher values of n-apt on the right , and apt-lp on the left. Thus, the aperture is markedly asymmetrical – wider on the left and higher on the right side.

Conclusions

1. In both analyzed groups of skulls, statistically significant asymmetry was observed, however, it is not homogeneous.

2. In medieval skulls, the most pronounced asymmetry was observed within the skull base, with dominance of left-sided dimensions.

3. In contemporary skulls, the most pronounced asymmetry was observed within the facial skeleton and also in the skull base. Within the skull base, dominance of left-sided dimensions was noted, within the facial skeleton – of the right-sided ones.

4. The largest variations were observed in the shape and localization of the foramina of the skull. It is associated with the differences of the position of the neurovascular elements which pass through these foramina.

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